Hodgen (J. T.)

VEGETABLE PHYSIOLOGY.

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By Prof. JOHN T. HODGEN.

Vegetable Physiology embraces every action of every part of vegetable matter, as a living organism. I do not, however, propose to embrace in a single lecture all that belongs to this interesting subject, but shall devote the present hour to the consideration of the circulation of the sap in plants, and the forces engaged in this action; also, the changes occurring in the circulating fluid, both while it is circulating, and as it accomplishes the object for which it was instituted in the development, growth, and nutrition of the vegetable tissues.

Sap is a solution in water of the materials necessary for the nourishment of a vegetable organism—a solution of three distinct classes of vegetable elements, salts, hydro-carbons, and azotized substances. Since water is the medium in which the other ingredients of the sap are dissolved, it merits a passing notice.

It may be taken up by roots embedded in the moistened earth, or absorbed by leaves bathed in an atmosphere always holding this fluid in solution.

It renders the solid elements mobile in the sap-vessels, and allows these solid materials to mingle one with the other, that they may, whilst circulating, accomplish such changes of proximate elements as may be necessary to the production of higher forms of matter.

Without being first dissolved, the starch, sugar, oil, and albuminous material of a grain of corn, could not be separated from the seed, and transmitted to distant parts, to form new arrangements of matter in the development of the root and stalk of the growing plant. Its uses, in the tissues of plants, are to render the parts pliable and elastic, and it also forms a considerable part of every plant, and remains so long as the plant is living. It is, finally, at least a considerable portion of it, lost by evaporation.

The salts being dissolved in water, are in this condition absorbed by the roots. They undergo changes in the plant, but enter and remain as elements of the sap, and tissues of the plant.

After having once gained admittance there is, ordinarily, no means by which they can be excreted.

The action of a selective power on the part of roots, in regard to this class of substances, is very marked.

Thus, the ash of duck-weed was found by Baussingault to contain 22 parts of potash to 10 parts of chloride of sodium, whereas the water in which the plant grew contained only 4 parts of potash to 10 parts of chloride of sodium. So, also, a selective power is exhibited in regard to sulphuric and phosphoric acid, as in the duck-weed; the relative

proportion of the sulphuric to the phosphoric acid is as 10 to 14 in the plant, and as 10 to 3 in the water. Sea water contains 25 parts of chloride of sodium, and 21 parts of chloride potassium; but plants growing in it contain more potash than soda. Also, plants growing on the same soil, and belonging to different species, have in their ash very different proportions of saline ingredients; and even parasites, that draw their nourishment directly from the sap of other plants, have not the same relative amounts of saline ingredients in their ash as the plants from which they draw their sustenance. So we conclude that the amount of the various salts present in the soil or water in which plants grow, furnishes no criterion by which we may judge the amount that they will absorb. The power of absorption of mineral solutions depends not so much on the character of the solution itself, or of the membranes, or roots themselves, as on the relations existing between the solution or liquid, and the membranes or roots. If an animal membrane be placed beeween water and alcohol, the water passes through the membrane into the alcohol; but if a sheet of India rubber be used instead of the animal membrane, then the alcohol passes through into the water; thus, the change of relations determines the direction of the flow. So, if many plants of different species grow upon the same soil, we must not expect them to absorb the saline materials with equal rapidity, or in equal proportions. There is no instinct or intuitive perception, no discernment; nothing but physical conditions are brought to bear in this selective power.

The hydro-carbons, such as starch, sugar, gum, and fat, are not taken into the plant as such, but are formed in the textures, out of material furnished by the water and air. They undergo many changes; the one being readily converted into another, and that without any marked change in chemical components; for, chemically, they are nearly identical, and may be exhaled, at least some of their ingredients, in the form of carbonic acid and water, by the union of their carbon and hydrogen with oxygen. The azotized substances are never absorbed in the form in which they are found in the tissues, though the distinguishing element of these compounds, nitrogen, must be present, being liberally furnished as nitric acid, which is formed during thunderstorms; and as ammonia, a product both of the decomposition of animal and vegetable substances, though nitric acid and ammonia are both readily soluble and absorbable in water.

The nitrogenized materials having been formed in the plant, there is no evidence of their decomposition until the process of germination sets up in the seed, when this vegetable albumen is the moving power or principle in the transformations that are necessary in the hydro-carbons to render them soluble, and thus portable in the primitive circulation of the germinating seed.

Having considered briefly the sources, conditions, and functions, of the proximate principles that enter into the structures of plants, we next proceed to examine the sap, as the material from which the various tissues are formed, and the agencies employed in its movements, the changes occurring during its existence as sap, and its transformation and deposition in the tissues.

The mineral ingredients, the nitrogenous materials, and, in part, the carbonic acid found in sap, are held in solution in the water that moistens the soil in which the roots of land plants are buried, and just here the circulation of the nutrient fluid begins; for, as the roots absorb the water, they exercise a sort of discriminating, or selective power, in regard to the quantity and quality of the substances dissolved in this almost universal solvent. From a soil moistened with water, holding in solution definite quantities of soda, potash, lime, magnesia, silica, and carbon, two plants, growing side by side, absorb very different proportions of these substances; and the proportion of the one or the other absorbed will depend upon the condition of the membrane, thin, delicate, homogeneous, as it is, that forms the wall of the spongioles or cell structures of the minute roots of the plants, and the fluids already existing on the inner side of these membranes; and the character of both of these has been determined by the nutritive actions that have formed the one, and modified the relative quantity of each of the ingredients of

the other, as well as changed the relations of the ultimate elements as the fluid approximates more nearly the condition of the tissues themselves.

Now, since only a part of the saline matters are absorbed, it is evident that the solution immediately in contact with the roots, after the absorption, is not precisely the same as that, only a line distant from the absorbing surface; and a difference, however slight, in the compositions of fluids that are near each other, and with no barrier to prevent their movements, causes them to rapidly mingle, and become uniform throughout.

To illustrate this point, we will take an example from Paget's Surgical Pathology. A crystal of alum, having a piece broken off, is placed in a saturated solution of the same substance. As soon as it is introduced, the water, immediately in contact with the broken surface, yields up a part of its alum, which is deposited on the surface of the crystal. The solution having lost a portion of its solid material, its specific gravity is changed, and this atom of water being lighter than those about it, immediately ascends, and another rushes in to take its place; this undergoes a similar change, and is similarly moved off, and so on, one after another, thus establishing a circulation in the fluids, which continues till its uniform composition is re-established, and in this way the circulation induced by the plant takes place, to bear the proper nutrient materials to the plant, and yet occurring entirely out side of the plant itself.

The second step in the circulating process is that which occurs in the passage of the fluid into the cells, which are the active selecting agents at the beginning of the minute roots; and here, what is most astonishing, this water, holding salts and nitrogenous matter and carbonic acid in solution, absolutely passes through a membrane in which there are no openings; it is not that the fluids passed into the open mouths of sap-vessels, but these cells are absolutely closed sacks with no openings however minute; and yet this watery solution of nutrient material passes, and that, too, with great rapidity and force, as it has been known to pass against a pressure of forty atmospheres, or 600 pounds to the square inch.

Water mingled with sand does not enter into the particles of the sand, but occupies the space between the grains.

Rob the sand of this water and the particles are not in the least degree changed in form, size or other properties; but as to these cells on the roots of plants, the water holding salts forms absolutely for a time a part of the cells. It is uniformly diffused through the cells in every part, just as soap is uniformly mingled with the water that forms the transparent walls of the bubble that so interests the observer of three summers' experience in the tangible things of this world. For a time, then, this saline solution forms a part of the cell wall; and since it differs from the materials that have undergone nutritive changes, and are within the sap vessels, and since liquids differing the one from the other, so far as the relation of their saline ingredients is concerned, are disposed to mingle with each other, the cell wall parts with a share of its liquid elements, which at once mingles with that in the sap vessels, while other portions of the saline ingredients of the soil mingle in a similar way, and form for a time a part of a cell; and thus the endosmotic current is kept up. Not that one generation of cells subserves this function for the whole period of the vegetable existence—not by any means; for these cells, being like the structure of the leaves, the more active parts of the vegetable organization undergo transformation more rapidly, and, if I may use the expression, die younger than the less active parts of the plants. Thus one generation of cells follows another; not that the dying cell forms the germ for that which is to take its place, for they do not sustain the relation of parent and offspring, but rather that of older and younger brothers laboring in the same cause, and as the older is exhausted, the younger takes his place, and the work goes continually on.

The third step in the circulatory process may be illustrated by the three following propositions, laid down by Professer Draper:

1st. If the force of attraction of the particles of a solid for those of a liquid be not equal to one-half of the cohesive force of the latter for each other, the liquids will refuse to pass through a pore of that solid

substance, and, in a capillary tube consisting of it, will be depressed below its hydrostatic level.

2d. If the force of attraction of the particles of a solid for those of a liquid exceeds half the cohesive force of the latter for each other, but is not equal to the whole force, the liquid will pass through a pore of that solid substance, and, in a capillary tube of it, will rise above its hydrostatic level.

3d. If the force of attraction of the particles of a solid for those of a liquid exceeds the whole cohesive force of the latter, chemical union between them ensues.

The second of the propositions is that which obtains between the sap vessels of plants and the sap itself, for here the liquid does pass through these capillary tubes; and through this agency, were there no other, the sap would reach the highest point of the loftiest tree, but could not go beyond the end of the sap-vessel; and through this agency alone, the materials for the nourishment of plants could not aid in further developing their structures; and when once filled, these vessels have no power to produce motion of the fluid within, for it matters not how small a tube may be, it cannot carry the water beyond its own substance; but if there be some means of removing the fluid when it reaches the end of the capillary tube, the place of that removed will be rapidly filled by the liquid next to it; and, if this be removed, another portion will rush in, and so on, thus keeping up a continual current, as is shown when the wick of a spirit lamp is left uncovered; or when the alcohol is burned off; or when the branch of a tree is cut off, and the end placed in a vessel of water, it will be found that the water disappears more rapidly than it would by evaporation from the surface alone; and this is precisely what occurs in the plant. A part of the water is carried off by evaporation from the surface of the leaves, thus aiding the flow of the sap through the capillary vessels of the sap wood. While the spongioles push the fluid forward, the evaporation acts as a sort of liberating agent, which empties the upper end of the vessels; and these act as suction pumps, drawing the fluid through the vessels. But the process of evaporation is not the only one that occurs on the leaves of plants; for, to use a very *crude* expression, the crude sap is here elaborated.

At this point it is expedient only to mention, that here carbonic acid is absorbed, and oxygen given off under the influence of sunlight; and this change, in connection with the change of inspissating the sap by evaporation, is sufficient to change its relation to the textures of the leaves, and to act as a propelling force to the sap, as will now be shown. The sap coming to the leaves is a thin, watery fluid, holding in solution salts and certain nitrogenized substances. After being elaborated, it is a thick, gummy liquid. Now, it is a well established fact, that in animal and vegetable tissues, pure water will push a solution of gum before it, if they be in opposite ends of the same tube; that is, that the pure water will more readily wet an animal or vegetable texture than will gum water; hence, we may regard the leaves as contested ground, where a struggle is constantly going on between crude sap and elaborated sap, and where crude sap is constantly forcing elaborated sap before it. The size and texture of the leaf determines, to a great extent, the rapidity of the flow of the sap in a plant. Thus, plants that have an abundance of foliage, and that are very vascular, will, as a rule, have the most rapid flow of sap; but we may go far back of the foliage for the conditions that determine the rapidity of the flow; for two plants, of the same species, growing, the one on a wet soil, and the other on a dry one, the first will have the larger leaves. Again, the condition of the atmosphere, so far as its watery vapor is concerned, has a remarkable effect. Plants growing in an atmosphere that is loaded with moisture, must have larger leaves to discharge the same amount of moisture that would evaporate from a smaller surface in a dry atmosphere.

We have, therefore, concluded what we desired to say in regard to the forces engaged in the circulation of the sap, except those that are due to nutritive changes effected in the tissues of the more solid parts of the plants. A few words will conclude all I have to say in regard to the food of plants.

This is always taken in a liquid or gaseous form; and, if gaseous, is

immediately dissolved on entering the circulation, though the spiral vessels contain an aeriform substance.

The salts, we need not mention farther than to say that their inorganic ingredients are gathered from the soil by the water that saturates it, and by the water taken into the roots.

Nitrogen is taken as ammonia and nitric acid. The first is formed abundantly by the decomposition of animal and vegetable substances, and forms a very small part of the atmosphere, from which it is thrown down by the rains and conveyed to the roots of plants. The second is produced during thunderstorms by the passage of electric sparks through watery vapors, also dissolved in water and thus absorbed. But salts, hydrogen, carbon, nitrogen, and oxygen, are far from being vegetable structures, though they are certainly the elements out of which vegetables are formed.

We cannot, perhaps, get a clearer insight into changes that occur during their organization than by observing the changes that occur in the plant during its fœtal life, or while it is dependent on the materials stored up in the seed for its nourishment, and upon which it lives exclusively for a time after it begins that action which is to result in the formation of an independent organization.

In the seed we have the germ; besides this, starch, fat, sugar, and an albuminous or nitrogenized substance, each bearing a proper relation to the other, and each refusing to be the first to make a move for life; and thus they may remain for centuries if no agent outside of themselves be brought to its aid. The seed is a combination of materials, a storehouse of valuable matter; but if locked up and unused will never change the relation of its own parts or its relation with surrounding objects; but give it water, and let a proper temperature be maintained, and important changes soon occur. Without heat no change can take place in its nitrogenous elements; and without water, when the atoms would move one from the other, or one towards another, to effect new combinations, they could not take a single step in the direction desired; and without motion, no organization could occur, nor could it be maintained did it already exist. The nitrogenized element, under the stimulus of heat and by the aid of water, begins a movement in the atoms of starch; presently the atom of starch forms a strong attachment for two atoms of water, a union is then effected, the starch becomes a bigamist, and sugar is formed. At this stage of development sunlight is not important; for germination proceeds rapidly in the dark so long as nutrient materials stored in the seed, starch, gum, sugar, and the like, furnish the materials for nourishing the forming tissues of the plant; indeed the air itself receives more from the embryonic plant than it furnishes to it; for if the seed be carefully weighed before germination, and the plant produced from it be carefully dried and weighed, it will be found that the plant actually weighs less than the seed from which it sprung. The carbonic acid given off during germination weighs more than the oxygen absorbed by it.

A very different state of things exists in the plant after it is weaned. I say weaned, for, when the stock of food stored up with the germ is exhausted, the plant is forced to gather from the soil in which its roots are imbedded, or from the air in which its leaves are bathed, the support which it obtained from the original stock formed and stored up for use by the parent plant. The process of growth, while the seed furnishes the materials for the plant, goes on more favorably if pure water be furnished it than if the water contains carbonic acid; but the reverse is true of an adult plant. Again, during the rapid growth of plants in the summer, the carbonic acid of the atmosphere is more rapidly taken up from the air than it is furnished to it by the various combustive processes that occur on the earth, and by the respiratory functions of animals; but during the winter the reverse is the case, for the animals exhale a larger amount of carbonic acid, fires burn more brightly and furnish large quantities to the air, whilst plants, during this cold period, absorb no carbonic acids at all from the air. Thus by opposing changes, effected in the air by vegetables and animals, it is maintained in a nearly uniform condition, varying slightly with the season; but the excess of carbonic acid formed in winter by the combustive and respiratory changes is checked in summer, and consumed by vegetable nutritive changes

during the summer, so that the rain, falling during early summer, when the young plants have set up an independent life, holds a larger proportion of carbonic acid in solution than at any other time; and this material is of great importance to the growth of plants, since carbon forms a large part of all their structures.

But carbon is not alone supplied by the water absorbed by the roots of plants; as the leaves and other parts absorb carbonic acid, and give off oxygen in the presence of sunlight. That sunlight is the agent that forces this act is shown by the fact, that during the night the carbonic acid absorbed in solution of water by the roots, is given off by the leaves and other parts of plants. Again, plants grown in darkness do not accumulate carbon, and only gain in weight by holding a larger proportion of water than entered into the formation of the seeds from which they grew. The green parts of plants, it has been taught, were the only parts that have the power of fixing carbon in the tissues; but that this power is not due to the green parts, is shown by exposing a perfectly white newly grown stalk to the light, when it immediately begins its function of fixing carbon, and soon assumes, as a consequence, a green color; and, although the green parts of plants are the most active agents in fixing carbon, aided by the force of sunlight, it is due rather to the fact that here the sap or blood of plants comes more nearly in contact with the atmosphere and is more exposed to light than in other parts covered with a thick bark, where the sap vessels are not so abundant nor in so exposed positions. The great object of vegetable organization seems to be to combine inorganic materials to form an organization that is to take certain salts of lime, magnesia, potash, soda, and the like, with oxygen, hydrogen, nitrogen and carbon, and blend them one with the other and form an organized structure. Now there is no possible combination of these elements that can form a tree or shrub, or indeed a single cell, simply because these elements are not all that enter into the formation of a cell, a plant, or an animal, even physically considered, but, as we have seen, light is essential to the growth of a plant after it has exhausted the limited supply stored in the seed from which it springs.

Heat, too, seems to exercise an important influence; for in plants grown under a vertical sun, or at that day, thickly obscured by the unnumbered years of the past, when the earth's internal heat was so great that the direct rays of a midsummer's sun, or the oblique glancings of his winter rays neither hastened nor retarded the growth of those plants that now form the deeper strata of our coal beds, marking them not with annual rings, by which we might determine the years required for their growth, but leaving them as silent records of the unvarying temperature in which they grew; while in regions farther removed, both in time and space, from an unvarying temperature, trees have each year of their existence recorded in their structures.

Again, both heat and light are lost, or to use a more favorite expression, are rendered latent in the growth of plants, and made sensible again by their decomposition or the return of their elements to their original condition as inorganic matter; and this is equally true, though not equally apparent, whether they return rapidly by active combustion, or slowly by *eremacausis*. Thus, then, as from the structures of plants, by decomposition, is given back to the inorganic world the materials that were drawn from it for their formation, so too the imponderable agents or forces, light, heat, and electricity, are restored to the universe at large.

So, if a certain amount of inorganic material is drawn from the earth and air, and a certain amount of force is borrowed from the sun for the development of plants, not only do we see the inorganic materials returned in the precise form in which they came, but the imponderable also are returned; not only so, but the carbonic acid, nitrogen and oxygen and hydrogen are restored to the air and water, and the saline materials are given back to the earth. Thus nothing is lost, nothing is gained, nothing is changed, except in point of form; and though carbon and hydrogen, with light and heat, may have been stored up in coal beds for millions of years, men are now searching the very bowels of the earth and restoring to the inorganic world its original matter in its original form. But vegetable matters do not always return to their inorganic state without still further modification; for all the animals of the earth

are dependent, either directly or indirectly, on the organizing force of plants for nourishment; for animals have not the power of taking these inorganic materials from the air, earth and water, and moulding their various organs and tissues from them, but the matter must first be elevated in the scale of organization before it can be appropriated by the higher forms of life; but even here it is in the end returned to the inorganic world, after having served as parts of both vegetable and animal structures, and performed the functions assigned it in the production of the varied phenomena of vegetable and animal life. So a vegetable or animal body may be likened to the flame of a lamp—a mere form, an outline—which represents inorganic matter undergoing organization and decomposition.

Thus, then, we find in the economy of nature nothing lost to the inorganic world; for the original igneous rocks, the air and the watery vapor and carbonic acid originally dissolved in it, contain all the chemical elements from which the myriads of vegetable and animal structures that have, for thousands of years, existed upon the earth were formed; and these organic forms are constantly returning to the inorganic world the materials that have been borrowed, and for a time have entered into new combinations. Nothing is lost, nothing is borrowed by the organic structures from the inorganic world that is not returned, not with usury, but without it—for the laws of usury are of human origin, and are not laid down by God, either in his written or natural revelation.